PRESERVATION, COMPOSITION, AND SIGNIFICANCE OF VICTORIAN LOWER TERTIARY 'CYCLAMMINA FAUNAS'

By D. J. TAYLOR

Department of Mines, Melbourne, Victoria

Abstract

A thorough taxonomic examination revealed that the foraminiferal genus *Cyclammina* is not present in the Lower Tertiary sediments of W. Victoria. The much simpler arenaceous genus *Haplophragmoides* had been originally misinterpreted because of preservation features, which resulted apparently from the chemical decay of the agglutinating cement of the test material. This decay allowed a gradual replacement with coarse, loosely bonded quartz grains, so that casts were formed. Interfingering between the quartz grains and original pyritic chamber infilling gave the impression of labyrinthic internal structures and the plucking of quartz grains from the surface suggested cancellate wall structure. This process of chemical decay may be linked with the weathering of pyrite to copiapite in the sands and silts.

Detailed study showed that specific content of the Paleocene *Haplophragmoides* assemblage differs from that of the Upper Eocene and a biostratigraphic scheme was substantiated with reference to associated planktonic foraminiferal faunas. This scheme is of correlative value and has led to the conclusion that the Johanna River Sands of the Aire Coast represent an abbreviated section of the Dilwyn Clay of the Princetown area.

Some species of *Haplophragmoides* are euryhaline, and would tolerate the envisaged paralic environments of the Lower Tertiary. Species of *Cyclammina* show a preference for bathyal or near bathyal depths.

Introduction

This paper reappraises the taxonomy of the Lower Tertiary '*Cyclammina* faunas' and evaluates their stratigraphic and environmental significance. The faunas studied are of Paleocene and Eocene ages and the stratigraphic ranges of the '*Cyclammina* faunas' are based on association with planktonic foraminiferal faunas. The study will show that local correlation is possible on the distribution of species within the '*Cyclammina* faunas' where other faunas are absent. Paleocene and Eocene marine sediments are only clearly developed in W. Victoria, to the W. of Cape Otway (Fig. 1), but correlation with '*Cyclammina* faunas' in other regions of Victoria is now possible. It will be shown also that there is a relationship, on specific level, between the Lower Tertiary '*Cyclammina* faunas' and the simple arenaceous Foraminifera of the genus *Haplophragmoides* described by Taylor (1964) from the Upper Cretaceous sediments in W. Victoria.

Chapman (1904) was first to describe arenaceous Foraminifera of the genus *Cyclammina* from the Victorian Tertiary sediments. This material was in silty sands from Johanna R., 8 miles W. of Cape Otway. From this material he described 2 new species, *Cyclammina complanata* and *C. paupera*. Later, Chapman & Crespin (1930) described *Cyclammina longicompressa* and *C. rotundata* from deep borings from Gippsland, in sediments regarded as Janjukian (Oligocene). Meanwhile, Chapman (1926) had examined New Zealand Foraminifera including *Haplophragmium incisum* Stache which Chapman regarded as being a *Cyclammina*. Chapman & Crespin (1932) then recognized *C. incisa* from Victoria.

The genus *Cyclammina* has become firmly established in the Australian geological literature to include bilaterally symmetrical, planispiral, arenaceous Foraminifera from the Tertiary sediments of southern Australia. In some sediments, the
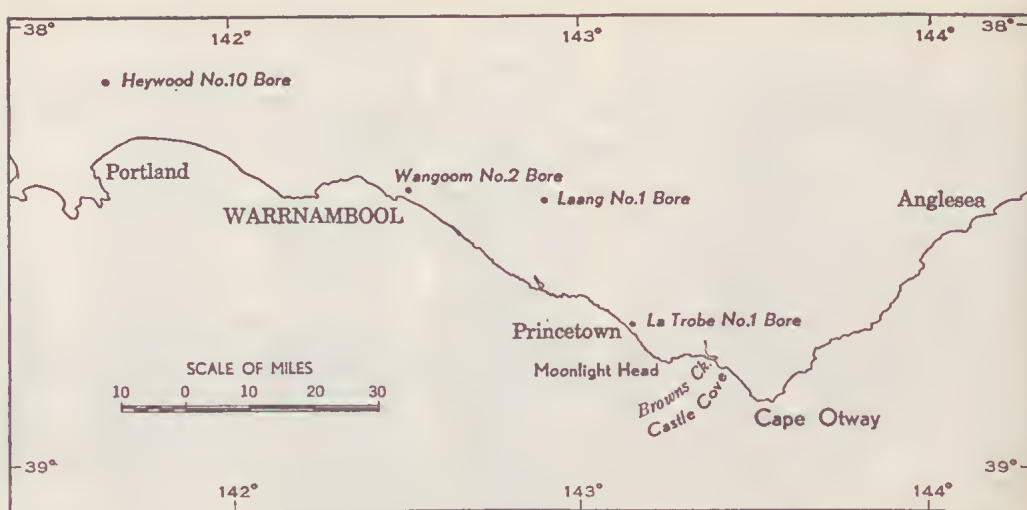
FIG. 1—Locality plan, W. Victoria.

specimens are of such a size that they are readily recognized in hand specimen. Attempts have been made to use these forms for local stratigraphic correlation (e.g. Baker 1953, Raggatt and Crespin 1955) and their presence in sediments have been interpreted to imply marine conditions when other faunas are absent.

This study has been implemented by recent drilling in W. Victoria, as subsurface samples contain well preserved 'Cyclammina faunas' associated with planktonic foraminiferal species, while outcrop samples of the 'Cyclammina faunas' are usually poorly preserved and seldom are associated with planktonic species.

All previously described and figured specimens of the Victorian 'Cyclammina faunas' have been examined, either in the Commonwealth Palaeontological Collection (Bureau of Mineral Resources, Canberra) or the Palaeontological Collection in the National Museum (Melbourne). Specimens figured in this paper are housed in the Geological Survey Museum, Melbourne. The registered numbers (prefixed GSM) are given with the figure explanations.

The 'Cyclammina Faunas'

STRATIGRAPHY OF THE 'Cyclammina'-BEARING SEDIMENTS

Two outcropping sections of 'Cyclammina'-bearing sediments are of particular interest:

(1) Moonlight Head to Princetown section (Baker 1953):

The basal Tertiary unit is the Pebble Point Formation of grits and sands which are ferruginized when weathered but often richly glauconitic when fresh. Above this are the silts, sandy silts, and glauconitic sands of the Dilwyn Clay. This unit contains the Rivernook Member, a glauconitic sandy clay, and the Princetown Member, a carbonaceous sandy silt, from which Baker (l.c.) reports Cyclammina. Many beds within the Dilwyn Clay are rich in pyrite and surface outcrops are stained by the iron sulphate, copiapite. The top of the Dilwyn Clay is not exposed.

This section is well demonstrated by continuous coring in the Mines Department's La Trobe No. 1 bore at Princetown. This bore extends below the Pebble

Point Formation into Upper Cretaceous sandy silts. These Upper Cretaceous beds are not present in surface outcrop where the Pebble Point Formation (Middle Paleocene, McGowran 1965) rests unconformably on Lower Cretaceous sediments.

(2) The Brown's Creek section (Raggatt & Crespin 1958, section 28; Carter 1958):

The basal Tertiary sands and silts rest unconformably on the Lower Cretaceous rocks. The basal unit is the Rotten Point Sands which consists of sands and grits with minor silty sands. Above this are the silty carbonaceous sands of the Johanna River Sands which are similar to part of the Dilwyn Clay. Unfortunately, there is no continuity of outcrop between the Johanna River Sands and the richly fossiliferous, Upper Eocene Brown's Creek Clays. The basal part of the Brown's Creek Clays are sandy silts which contain planktonic Foraminifera.

Driling to the W. of Princetown shows a repetition of the Moonlight Head to Princetown section with equivalents of the Brown's Creek Clays on top. In some drilled sections (e.g. Laang No. 1) the basal sandy silts are much thicker than the marls and calcareous silts which are characteristic of the Brown's Creek Clays. These Upper Eocene sandy silts often contain good 'Cyclammina faunas'. It is noted that the lithological equivalents of the Brown's Creek Clays cannot be recognized in the La Trobe No. 1 section.

PRESERVATION

In the Moonlight Head to Princetown section the dark carbonaceous siltstones yield few if any calcareous Foraminifera. Only a few sandy horizons (e.g. the Pebble Point shell bed and the Rivernook Member) contain rich calcareous foraminiferal faunas. However, the silts contained better faunas in the La Trobe No. 1 section than did the sands. The bore samples of the silts were rich in pyrite but, in outcrop, pyrite is seldom in its original state and copiapite is present. Edwards and Baker (1951) show that weathering of pyrite results in the formation of copiapite and jarosite in the Lower Tertiary silts and sands at Anglesea (to the E. of Cape Otway). Such a reaction could release sulphuric acid which, when added to the ground water, would dissolve calcareous foraminiferal tests. This reaction is inferred from the fact that copiapite-bearing sediments seldom contain calcareous Foraminifera while identical sediments in fresh condition contain unaltered pyrite and calcareous Foraminifera.

The arenaceous 'Cyclammina faunas' are found at several horizons in outcrop in the Princetown section but are poorly preserved and as Baker (1953) states 'cannot be isolated from the matrix without crumbling'. The term arenaceous Foraminifera suggests that they are composed of sand grains which implies that they are resistant to chemical action when compared with calcareous forms. However, the term agglutinated Foraminifera is more accurate as the tests are made up of sand grains agglutinated by an organic cementing medium. Hedley (1963) shows that the cementing medium is bonded by ferric iron and calcium. Hedley's experimental data show that agglutinated tests crumble when ferric iron and calcium is removed by use of a synthetic sequestering agent. It is assumed that this reaction takes place on weathering and/or on contact with ground water in the W. Victorian Lower Tertiary sediments and it is assumed that this reaction is linked with the decomposition of pyrite. Also of possible significance is the fact that well preserved specimens in the 'Cyclammina faunas' are usually infilled with pyrite, while in more poorly preserved specimens the pyrite appears to be altered.

A gradual process of test decomposition and replacement can be recognized as three preservation stages which are illustrated in Fig. 2 and discussed below:

(I) The original test material (Fig. 2a). Test walls are usually fine grained and smooth. When pyrite test infilling is not present the tests exhibit chamber collapse. Original test material has only been recognized in the sands and silts in subsurface section. In calcareous sediments the original test material is common, even in outcrop specimens.

(II) Partial replacement casts (Fig. 2b, c). Outer test walls consist of a rough skin of quartz grains with a suggestion of inward quartz crystal growth which interfingers with the pyrite chamber infilling. Little if any of the original outer test wall remains, although the septa and preceding whorls are of original test material. In a single specimen this partial replacement appears to be a very gradual process,
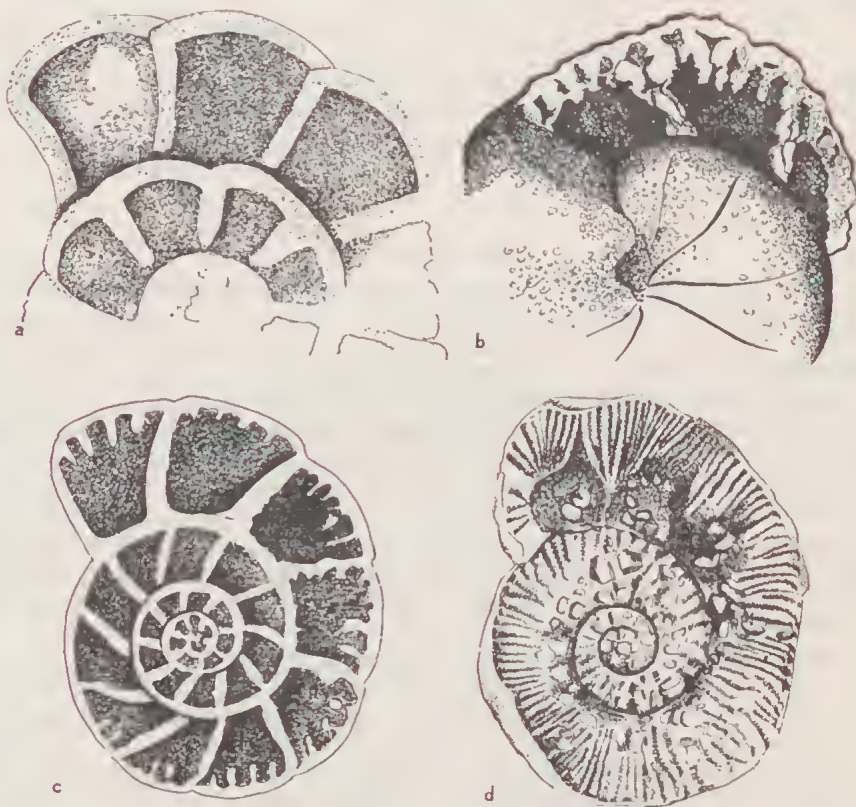

Fig. 2—Preservation stages.

a—Stage I—*Haplophragmoides complanata* (Chapman). Thick section. Diameter 0·6 mm. (GSM 60464)

b—Stage II—*H. complanata* (Chapman). Dissected specimen. Diameter 0·76 mm. (GSM 60465)

c—Stage II—*H. complanata* (Chapman). Thick section. Diameter 0·8 mm. (GSM 60466)

d—Stage III—*H.* cf. *incisa* (Stache). Thick section. Diameter 2·5 mm. (GSM 60467)

All figured specimens are from La Trobe No. 1 bore, a-c at 980 ft, d at 200 ft.

being further advanced in later chambers than in the earlier chambers of the last whorl, as is illustrated in Fig. 2c. This stage is present in both surface and sub-surface material. It is the stage of preservation of the holotypes of *Cyclammina complanata* Chapman and *C. paupera* Chapman.

(III) Ghosts or complete replacement casts (Fig. 2d) consist of grains and crystals of quartz with disseminated grains of partially altered pyrite. External suture lines are present but there is no trace of internal features such as septa. This final stage still retains cohesion as long as the specimens remain relatively undisturbed. It is the common stage in outcrop specimens as well as sub-surface samples.

In both stages II and III plucking of quartz grains from the test surface is common and this has been misinterpreted as indicating cancellated wall structure. This misinterpretation resulted in generic misidentification.

Another preservation feature is test distortion, which is taxonomically confusing at the specific level. In the more plastic marls and calcareous silts of the Upper Eocene and Oligocene, test distortion is common, especially in deep sub-surface section, no doubt due to compaction. This distortion is much more common in the arenaceous than in the calcareous Foraminifera, probably due to the structural instability of the cementing media in arenaceous forms as opposed to the crystalline structure of the calcareous forms. The direction of distortion is slightly angled to the axis of coiling with the final face asymmetrical. This preferred distortion direction may indicate a preferred burial position. Chapman and Crespin (1930) have noted apparently distorted specimens in Gippsland deep bores but, because of their abundance, have erected the species *Cyclammina longicompressa*. The author has examined many samples containing forms resembling *C. longicompressa* and considers them to be distorted forms of at least two described species.

The mode of preservation of the 'Cyclammina faunas' made it difficult to cut thin sections. The best methods of study were found to be the cutting of thick sections, whole mounts in xylol or canada balsam, and dissection. These preparations were then drawn, as photographs lacked clarity of detail.

Generalized Test Morphology

The original test material is fine grained and externally smooth with narrow sutures. The septa are composed of fine grained material and are wider than the sutures. The pyritic chamber infilling shows clearly that the chamber walls including the septa, are simple without any labyrinthic or cancellate structures. The apertures are single equatorial marginal slits and there are no external or internal indications of multiple apertures.

Taxonomic Notes

From the generalized morphology the generic status of the 'Cyclammina faunas' will now be discussed. Purely for convenience in discussion, the phylogenetic order at subfamily level is reversed from that given by Loeblich & Tappan (1964). The generic diagnoses are those schematically given by Maync (1952, p. 52-53).

Family Lituolidae de Blainville 1825

Subfamily Cyclammininae Marie 1941

Genus **Cyclammina** Brady 1879

Diagnosis: Interior structure complex with alveolar hypodermis and/or labyrinthic interior structure of wall and septae. Multiple cribrate apertures with additional horizontal, interiomarginal slit at base of apertural face.

DISCUSSION: It is evident from the generalized test morphology that the 'Cyclammina faunas' do not comply with this diagnosis, either in interior structure or apertural detail. The quartz and pyrite interfingering of preservation stages II and III have been mistaken as alveolar hyperdermis or labyrinthic structure. Chapman (1904) described these preservation features as 'internal cancellated structure' in *Cyclammina complanata* when, in fact, it was the result of quartz plucking, as can be shown by wetting the holotype with xylol.

It is concluded that the genus *Cyclammina* is not present in the W. Victorian Lower Tertiary sediments.

Genus **Alveolophragmium** Shchedrina 1936

DIAGNOSIS: Interior structure as for *Cyclammina*, but sutures not clearly developed. Aperture a curved interiomarginal slit at the base of the apertural face.

DISCUSSION: Internal structural details differ from W. Victorian material.

Other genera in this subfamily differ even more radically from those discussed in respect to the 'Cyclammina faunas'. It is apparent that the W. Victorian Lower Tertiary 'Cyclammina faunas' are not within the Cyclammininae.

Subfamily HAPLOPRAGMOIDINAE Maync 1952

Genus **Haplophragmoides** Cushman 1910

DIAGNOSIS: Planispirally coiled at all stages, test more or less involute. Aperture a simple interiomarginal slit at the base of apertural face. The internal walls are simple.

DISCUSSION: The species of the 'Cyclammina faunas' all agree with this diagnosis and thus are all members of the genus *Haplophragmoides*.

Haplophragmoides complanata (Chapman)
(Fig. 2 a-c; 3 (1), (2))

1904   *Cyclammina complanata* Chapman, p. 228, Pl. 12, fig. 12.

DIAGNOSIS: Somewhat compressed, discoidal, biumbilicate test, with subrounded periphery, undulate in outline. Outer whorl with 10-12 chambers with curved, narrow, slightly depressed sutures. The later chambers show an evolute tendency. Deep umbilicus. The original external wall of the test is smooth and fine grained but most specimens exhibit test replacement. The average diameter is 0·8 mm. The ratio of diameter to thickness is 5 : 2.

DISCUSSION: This species has been ignored by workers subsequent to Chapman, apparently because it was not realized that the number of partially evolute chambers depends on the maturity of the specimen. Chapman's holotype has a maximum diameter of 1·9 mm which is unusually large, and it has 5 partially evolute final chambers. The largest specimen found by the author was 1 mm in diameter with 3 partially evolute chambers. Even the smallest specimens exhibit a tendency towards evolute coiling and this, together with the deep umbilicus, distinguishes the species from *H.* cf. *incisa* which apparently developed from *H. complanata*. This lineage is discussed below and shown on Fig. 5.

DISTRIBUTION: This form is recognized only in W. Victoria. It is associated with and present above Paleocene planktonic faunas but is never associated with Upper Eocene or younger planktonic faunas. This species is not reported from the W. Victorian Upper Cretaceous faunas. Holotype from Chapman's Sample No. 1, Brown's Creek (= base Johanna River Sands).

FIG. 3

(1) a, b—*Haplophragmoides complanata* (Chapman) from La Trobe No. 1 bore
   at 980 ft. Diameter 0·62 mm, thickness 0·25 mm. (GSM 60456)
(2)—*H. complanata*, from ibid at 420 ft. Diameter 1 mm, thickness 0·45 mm.
   (GSM 60457)
(3) a, b—*Haplophragmoides* cf. *incisa* (Stache) from Laang No. 1 bore at
   2150 ft. Diameter 2·1 mm. Distorted specimen. (GSM 60458)
(4) a, b—*H.* cf. *incisa* ibid. Diameter 2·1 mm, thickness 0·9 mm. (GSM 60459)

B

Haplophragmoides cf. incisa (Stache)

(Fig. 2 a; 3 (3), (4))

?1864   *Haplophragmium incisum* Stache, p. 165, Pl. 21, fig. 1.
?1926   *Cyclammina incisa* (Stache), Chapman, p. 29, Pl. 2, fig. 1.
 1932   *Cyclammina incisa* Chapman & Crespin, Pl. 1, fig. 6.
 1950   *Cyclammina incisa* Crespin, p. 72, Pl. 10, fig. 3.
 1955   *Cyclammina incisa* Crespin, in Raggatt & Crespin, Pl. 7, fig. 3.
 1930   *Cyclammina longicompressa* Chapman & Crespin, p. 97, Pl. 5, fig. 3, 384.

DIAGNOSIS: Large robust form, often visible to naked eye. External features similar to *H. complanata,* but completely involute and with a more enclosed, shallower umbilicus. Usually with roughened exterior; seldom found with original external wall.

The largest specimens are of 5 mm diameter but average diameter is of the order of 2 mm, though in some samples the average diameter is smaller. Ratio of diameter to thickness varies from 2:1 to 5:2.

DISCUSSION: On external features this species agrees with Chapman's figure of *Cyclammina incisa* (Stache) from the New Zealand Eocene and Oligocene (refer Hornibrook 1961, p. 30). As already mentioned, the Victorian material is not referable to *Cyclammina,* so the specific identification must be queried for the Victorian form. However, Hornibrook (l.c.) does cast some doubt on the generic identity of the New Zealand form.

On examination, the holotype and paratype of *C. longicompressa* were considered to be distorted specimens of *H.* cf. *incisa.* The asymmetry of the final face is significant and is illustrated in Fig. 3 (3).

H. cf. *incisa* is closely related to *H. complanata.* In considering the La Trobe No. 1 sequence (Fig. 5), specimens of *H. complanata* show an evolutionary tendency. This tendency is shown by a reduction of number of partially evolute chambers with an increase in overall size of specimens, and is linked with a gradual closing and filling of the umbilicus. Finally, all specimens at 200 ft are completely evolute and are typical of *H.* cf. *incisa.* Although specimens are not present in every sample between 1100 ft and 200 ft, it is assumed that there is a single lineage from *H. complanata* to *H.* cf. *incisa.* The segmentation of such a lineage is extremely difficult, depending on the choice of a criterion which by necessity must be regarded as arbitrary. The major evolutionary tendency, in the above lineage, is the development of a completely involute form, linked with the closing of the umbilicus. These are 2 of the 6 characters in the genus *Haplophragmoides* which are regarded as being of specific consequence by Taylor (1964, p. 563). Thus, a completely involute test is taken as the criterion for *H.* cf. *incisa,* while a partially evolute test is the criterion for *H. complanata.* But with such single forms it is imposisble to draw a sharp line of segmentation. It is predictable that there would be overlap and such is evident in the sample from 420 ft, where completely involute specimens are associated with specimens showing one partially evolute chamber. In all probability these two forms are conspecific. No one specimen in this sample can be regarded as a transition form between *H. complanata* and *H.* cf. *incisa,* but the whole sample can be regarded as a transition sample (? population) of the lineage at this level. Although theoretically incorrect, it is most convenient to list both *H. complanata* and *H.* cf. *incisa* in the 420 ft sample.

Size is another character which distinguishes *H. complanata* from the larger *H.* cf. *incisa.* This factor may be of value but is probably influenced also by environment. Generally speaking, specimens became larger as the lineage progressed.

DISTRIBUTION: *H.* cf. *incisa* is associated with Upper Eocene and younger planktonic faunas. It does range below definite Upper Eocene but is not associated with Paleocene and older faunas.

Haplophragmoides sp. B Taylor
(Fig. 4 (3))

1964   *Haplophragmoides* sp. *B* Taylor, p. 565, Pl. 74, fig. 4.

DIAGNOSIS: Small, fairly rotund, deeply umbilicate, loosely coiled form. 6-8 chambers in outer whorl. In some specimens, all chambers in outer whorl are partially evolute. The later or all sutures are thickened. In Tertiary specimens the maximum diameter ranges from 0·2 to 0·4 mm while in the Upper Cretaceous the maximum diameter is 0·7 mm. Ratio of diameter to thickness is 2 : 1 in Paleocene specimens.

DISCUSSION: This form may be related to *H. complanata*, but this cannot be established. *H.* sp. *B* and *H. complanata* have been found associated only in two samples, so that a suggestion that the former is an immature form of the latter cannot be clearly supported. For this reason, an informal designation has been continued, rather than giving it a valid specific designation.

DISTRIBUTION: Common throughout the W. Victorian Upper Cretaceous sequence. Has been found only at 960 ft in La Trobe No. 1 and at 2500 ft in Wangoom No. 2 bores associated with 'Rivernook faunas' (upper Paleocene).

Haplophragmoides paupera (Chapman)
(Fig. 4 (1))

1904   *Cyclammina paupera* Chapman, p. 229, Pl. 22, fig. 6.
1964   *Haplophragmoides* sp. *A* Taylor, p. 563, Pl. 74, fig. 3.

DIAGNOSIS: Delicate test with acute periphery, the final face being triangular in outline with definite apex. Deep umbilicus with prominent and flattened umbilical margin. Original test material is usually preserved even in outcrop samples. Maximum diameter of specimens ranges from 0·5 mm to 1·3 mm. Ratio of diameter to thickness is 3·5 : 1.

DISCUSSION: The acute periphery and the deep umbilicus are distinctive features. Both Upper Cretaceous and Paleocene specimens are identical with Chapman's holotype, apart from size variation. The original test material is very fine grained and chamber collapse is a common feature, so that some specimens do superficially resemble the Upper Cretaceous species *H. excavatus* Cushman & Walters.

DISTRIBUTION: Upper part of the Upper Cretaceous sequence (Taylor 1964). Also associated with Paleocene planktonic faunas but never with younger planktonic faunas. Holotype from Chapman's Sample No. 1, Brown's Creek (= base Johanna River Sands).

Haplophragmoides cf. paupera (Chapman)
(Fig. 4 (2))

1950   *Cyclammina paupera* Chapman, Crespin, p. 72, Pl. 10, fig. 4.
1955   *Cyclammina paupera* Chapman, Crespin, in Raggatt & Crespin, Pl. 7, fig. 4.

DIAGNOSIS: Compared with *H. paupera*, *H.* cf. *paupera* is a more robust, thicker, and generally larger form. The average diameter of specimens is 1·5 mm and the ratio of diameter to thickness is 3 : 1. Although this form is flattened umbilically and exhibits peripheral thinning, it does not have the prominent umbilical margin or the peripheral acuteness of *H. paupera*. The absence of the
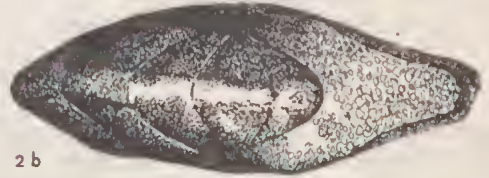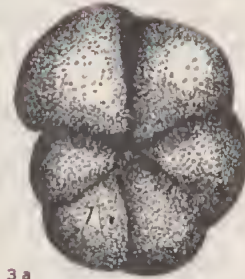
1 a

2 a

1 b

2 b

4 a

3 a

3 b

4 b

prominent umbilical margin reflects the fact that this form has a shallow closed umbilicus, compared with the deep open umbilicus of *H. paupera*. This form lacks the pseudo-keel which causes the peripheral acuteness in *H. paupera*. The original test material is never as fine-grained as that of *H. paupera*.

DISCUSSION: The differences between *H. paupera* and *H.* cf. *paupera* are morphologically a matter of degree. They are obviously parts of one lineage and this has not reached a stage where specific fragmentation can be justified on the criterion of peripheral acuteness or of umbilical features. The development seems to be towards a more globular form.

DISTRIBUTION: *H.* cf. *paupera* is associated with *H. paupera* in the Paleocene, while this form continues up into the Upper Eocene and younger sediments, where *H. paupera* is not present. This is the form illustrated by Crespin (1950) from the Demons Bluff Formation at Anglesea.

Haplophragmoides rotundata (Chapman & Crespin)
(Fig. 4 (4))

1904   *Haplophragmium latidorsatum* Chapman (non Brady), p. 227, Pl. 22, fig. 1.
1930   *Haplophragmoides rotundata* Chapman & Crespin, p. 96, Pl. 5, fig. 1, 2.
1950   *Haplophragmoides rotundata* Chapman & Crespin, p. 72, Pl. 10, fig. 5.
1955   *Haplophragmoides rotundata* Chapman & Crespin, Crespin, in Raggatt & Crespin, Pl. 7, fig. 5.
1964   *Haplophragmoides* sp. *C* Taylor, p. 564, Pl. 74, fig. 5.

DIAGNOSIS: Somewhat flattened, subglobular, completely involute test of 6-8 chambers with no umbilical hollow. External walls are usually coarse grained though occasional fine grained specimens have been noted. The average diameter of Paleocene specimens is 0·7 mm, while the larger Upper Eocene specimens are 1 mm. The ratio of diameter to thickness is 5:3.

DISTRIBUTION: The holotype is from Oligocene (Janjukian Stage) sediments. This species first appears in the upper part of the W. Victorian Upper Cretaceous sequence and is common throughout the Lower Tertiary and probably extends into the Miocene.

Stratigraphic Distribution of *Haplophragmoides* Assemblages

This paper is part of a study of the Lower Tertiary foraminiferal faunas sediments in W. Victoria. Extensive correlations and conclusions can only be made on considering the overall foraminiferal faunas, so that correlations and environmental interpretations made here are only preliminary until all the accumulated facts are published. A detailed faunal analysis of the La Trobe bore and other Paleocene bore sections is in progress.

'Cyclammina' in Victoria has been regarded as a 'facies fossil' and thus of no stratigraphic significance by some workers. 'Facies fossil' must be regarded as an invalid term as all fossils are influenced by facies. The author's work on the La Trobe

---

FIG. 4
(1) a, b—*Haplophragmoides paupera* (Chapman) from La Trobe No. 1 bore at 980 ft. Diameter 0·7 mm, thickness 0·2 mm. (GSM 60460)
(2) a, b—*H.* cf. *paupera* from Laang No. 1 bore at 2150 ft. Diameter 1·4 mm, thickness 0·5 mm. (GSM 60461)
(3) a, b—*Haplophragmoides* sp. *B* Taylor from La Trobe No. 1 bore at 960 ft. Diameter 0·3 mm, thickness 0·13 mm. (GSM 60462)
(4) a, b—*Haplophragmoides rotundata* (Chapman & Crespin) from ibid. Diameter 0·6 mm, thickness 0·25 mm. (GSM 60463)

section shows that even the planktonic Foraminifera are influenced by facies. The section on palaeoecology which follows shows that *Haplophragmoides* spp. would be expected in the envisaged environments of the Lower Tertiary of W. Victoria and that both their lateral and vertical distribution would be more constant than that of most other foraminiferal genera. Thus, any vertical distribution of species of *Haplophragmoides* would be useful in correlating sediments where they are the only forms present. However, any biostratigraphic scheme can be only of local biostratigraphic value if it is based solely on the vertical distribution of species of such a morphologically conservative genus as *Haplophragmoides*. Such a scheme is feasible only if it is based on the association of these species with species of precisely known stratigraphic range, such as planktonic Foraminifera.

Study of the La Trobe, Laang, and other bore sections shows that one assemblage of *Haplophragmoides* spp. is always associated with Paleocene planktonic Foraminifera, while a different assemblage of *Haplophragmoides* spp. is associated with Upper Eocene planktonic Foraminifera. Difficulty arises in the terminology of these associations as the one assemblage of *Haplophragmoides* spp. may occupy the same interval as several distinct assemblages of planktonic Foraminifera, as in the Upper Eocene (Carter 1958). The status of the two types of assemblages differs in that the planktonic species are widespread, while the *Haplophragmoides* spp. are of local significance only. Thus, such terms as zone or zonule should be reserved for the smaller intervals with distinct assemblages of planktonic species. For these reasons the loosely defined term '*Haplophragmoides* assemblage' is used, prefixed with time stratigraphic terms 'Paleocene' and 'Upper Eocene'. This may appear a confusion of terms, but it is emphasized that the whole scheme is based and substantiated on association with planktonic Foraminifera. The term 'Paleocene *Haplophragmoides* assemblage' is but a short way of saying 'the *Haplophragmoides* assemblage associated with Paleocene planktonic species'.

THE *Haplophragmoides* ASSEMBLAGES

THE PALEOCENE *Haplophragmoides* ASSEMBLAGE: Between 1050 and 678 ft in the La Trobe bore, a distinct assemblage of *Haplophragmoides* spp. is associated with such planktonic Foraminifera as *Globorotalia aequa* Cushman & Renz, *G. chapmani* Parr, *G. pseudomenardii* Bolli, and *G. imitata* Subbotina. McGowran (1965) has recorded these species from nearby outcrop samples and gives considerable evidence that they are of Paleocene age, probably representing the Upper Paleocene.

Fig. 5 shows that the above planktonic species are associated with a *Haplophragmoides* assemblage consisting of:

> *H. complanata*
> *H. paupera*
> *H. rotundata*
> *H.* cf. *paupera* (rare)
> *H.* sp. *B* (one sample only).

Definite Paleocene samples from other bores (e.g. Wangoom 2 at 2500 ft, Heywood 10 at 4120 ft, and Laang 1 at 2630 ft) always contain the first 3 listed species.

THE UPPER EOCENE *Haplophragmoides* ASSEMBLAGE: Fig 5 shows that a different *Haplophragmoides* assemblage is associated with such planktonic species as *Globigeraspsis index* (Finlay), *Hantkenina alabamensis compressa* Parr, and *Pseudohastigerina micra* (Cole). Carter (1958) shows that these planktonic species
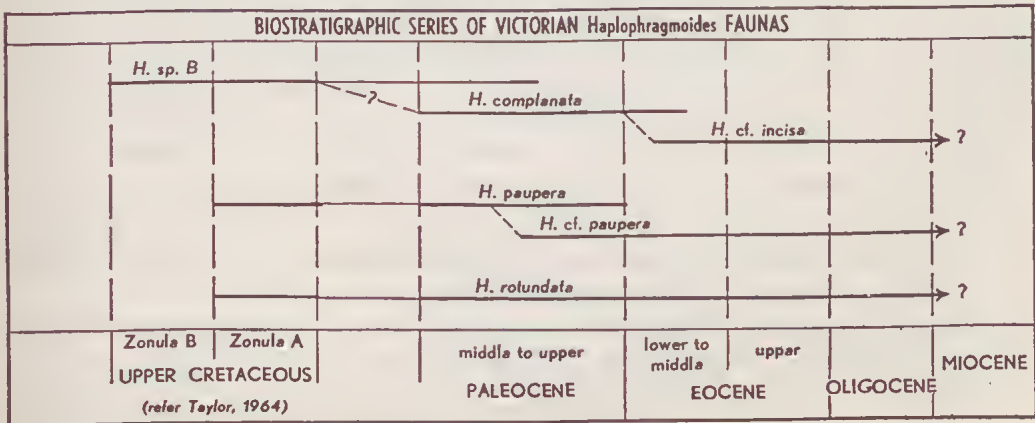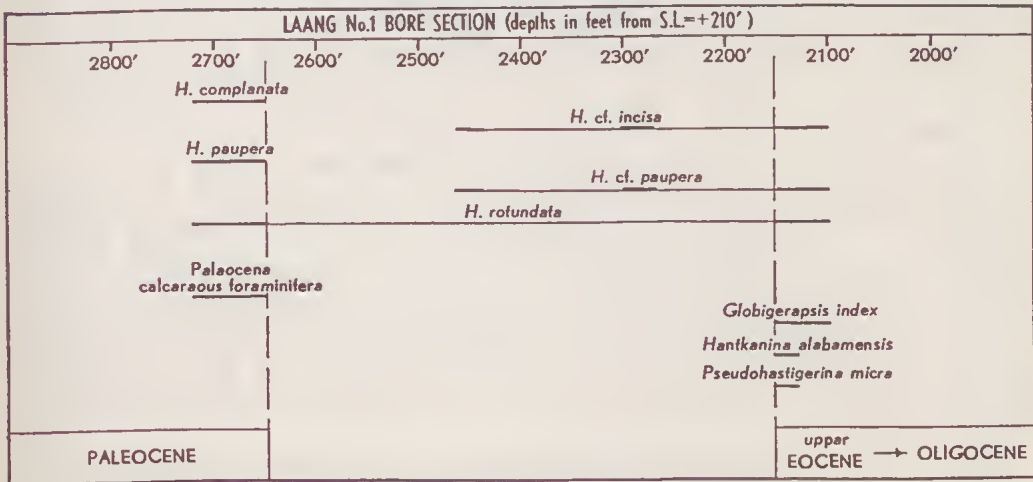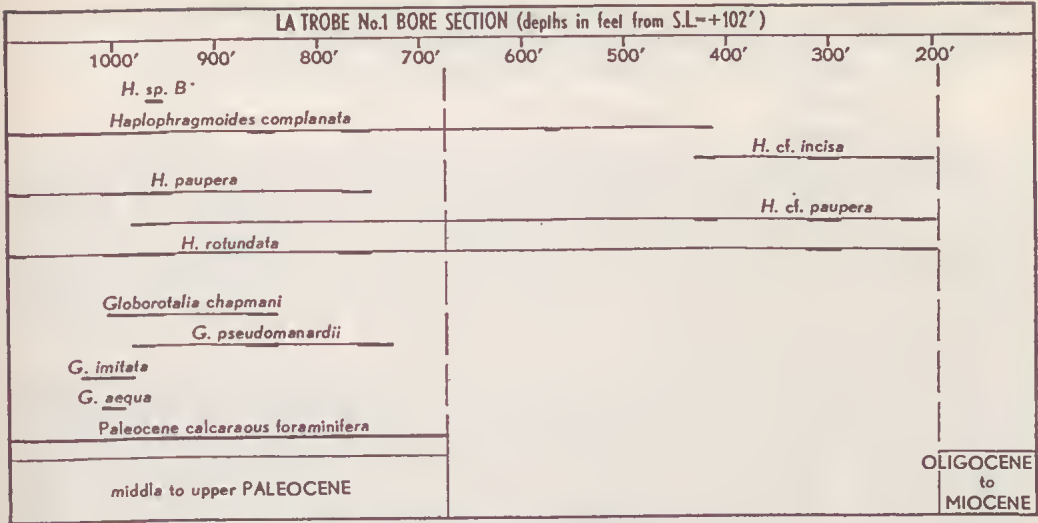
FIG. 5—Stratigraphic distribution of Lower Tertiary *Haplophragmoides* faunas in association with planktonic foraminiferal faunas.

indicate an Upper Eocene age. In the Laang 1 bore these planktonic species are associated with a *Haplophragmoides* assemblage consisting of:

H. cf. *incisa*
H. rotundata
H. cf. *paupera.*

Definite Upper Eocene outcrop samples from Brown's Creek, as well as bore samples, contain the above assemblage, though often *Haplophragmoides* spp. are rare or absent in Upper Eocene faunas which are rich in calcareous species. It is noted that this assemblage is present in the Oligocene (Janjukian Stage) and Lower Miocene. The upper limit of this fauna has not been determined. This Upper Eocene *Haplophragmoides* assemblage is present at 200 ft in the La Trobe section but planktonic species are absent.

THE *Haplopragmiodes* ASSEMBLAGE BETWEEN THE PALEOCENE AND UPPER EOCENE: As discussed in the taxonomic notes, *H.* cf. *incisa* is probably a linear development from *H. complanata* and the exact point of specific fragmentation is difficult in this lineage. This is evident at 420 ft in the La Trobe section where there is an apparent association of the two forms, together with *H. rotundata* and *H.* cf. *paupera.* But such an assemblage has not been found associated with either Paleocene or Upper Eocene planktonic Foraminifera. It is noted that Lower and Middle Eocene planktonic faunas have not been recognized in W. Victoria, although Ludbrook (1963) reported them from South Australia. At present the author does not place any stratigraphic value on the *H. complanata-H.* cf. *incisa* association, except that it occurs between definite Paleocene and definite Upper Eocene.

UPPER CRETACEOUS *Haplophragmoides* ASSEMBLAGES: Taylor (1964) has already shown a stratigraphic distribution of *Haplophragmoides* spp. in the Upper Cretaceous of W. Victoria and this is summarized in Fig. 5. It is apparent that the highest Upper Cretaceous *Haplophragmoides* assemblage is similar in specific content to the Paleocene assemblage, except that *H. complanata* is absent in the former and *H.* sp. *B* is rare in the latter. It should be noted that Taylor (l.c.) found an interval of sediment barren of Foraminifera between the highest Upper Cretaceous fauna and the lowest Tertiary fauna. This is so in the La Trobe 1, the lowest Tertiary fauna being at 1200 ft and the highest Cretaceous fauna at 1627 ft.

SUMMARY OF ASSEMBLAGES: A *Haplophragmoides* assemblage of two or more species and not an individual species is the unit of correlation in the above scheme. This is because the scheme is based on the apparent linear evolution of two groups of species in such a conservative genus as *Haplophragmoides*. These two species groups are (a) the *H. paupera* group and (b) *H. complanata* → *H.* cf. *incisa* group which may have developed from the Cretaceous species *H.* sp. *B*. The overlap of members of the one linear evolutionary group adds weight to this scheme.

Upper Cretaceous-Senonion—*H.* sp. *B* and *H paupera.*
Upper Cretaceous-post Senonian—no Foraminifera found. Could have marked development of *H.* sp. *B* → *H. complanata.*
Paleocene—Middle to Upper—*H. complanata* with very rare *H.* sp. *B*, and *H. paupera* with the more robust *H.* cf. *paupera.*
Eocene—Lower to Middle—an overlap between *H. complanata* and *H.* cf. *incisa*, and *H.* cf. *paupera* without *H. paupera.*
Upper Eocene—*H.* cf. *incisa* without *H. complanata* but with *H.* cf. *paupera.*
Oligocene to Miocene—the Upper Eocene assemblage extends upwards to at

least the Lower Miocene. The Upper Eocene age of an assemblage can be determined by the assemblage and by superposition in the section; that is, it is below the widespread Janjukian (Oligocene) limestones.

STRATIGRAPHIC CORRELATION

Correlations can now be given of outcropping sections where *Haplophragmoides* spp. are present without the association of other forms which would provide more precise correlation.

THE LA TROBE NO. 1 SECTION: This is the basic section for correlation of the *Haplophragmoides* assemblages even though definite Upper Eocene associations are absent.

MOONLIGHT HEAD TO PRINCETOWN SECTION: McGowran (1965) has shown that the Pebble Point shell bed and the Rivernook Member are Paleocene. Harris (1965), on microfloral evidence, suggests that the exposed Dilwyn Clay is of Paleocene age. Near the top of the exposed section is the Princetown Member in which Baker (1953) recorded *Cyclammina*. The author considers that this record of *Cyclammina* is, in fact, the Paleocene *Haplophragmoides* fauna and, at a later date, will provide additional evidence to show that the Princetown Member can be correlated with the 750 ft level in La Trobe 1. Between the Princetown Member and the Clifton Formation (Oligocene) the section is covered.

BROWN'S CREEK SECTION: Chapman's (1904) original material came from samples which were:

Sample No. 1—'an ochreous brown clay, almost chocolate coloured when wet' (Chapman l.c. p. 227). The sample is probably from the same horizon as Raggatt & Crespin's (1955, p. 134, section 28) 'grey to purplish brown shale with *Cyclammina*'. Chapman's sample contained *Haplophragmoides complanata* and *H. paupera* which is an assemblage regarded here as being Paleocene.

Sample No. 2—'dark brown to black pyritous and sandy clays' which contained 'few foraminiferal tests' (Chapman l.c.). This sample was probably of the highest exposed beds of the Johanna River Sands, which are in a 'washout' on the W. bank of Brown's Creek. Chapman lists nothing diagnostic in his sample, but the author has collected samples from this locality which contained poorly preserved *Haplophragmoides* spp., probably referable to the Upper Eocene assemblage. Unfortunately, the contact is covered between the Johanna River Sands and the richly fossiliferous Brown's Creek Clays of Upper Eocene age.

It is concluded that the lower part of the Johanna River Sands is Paleocene and the upper part is Upper Eocene. This would imply that the Johanna River Sands can be equated with the Dilwyn Clay between 200 ft and 1170 ft in the La Trobe section. However, Raggatt (in Raggatt & Crespin 1955, section 28) measured only 80 ft of Johanna River Sands with a 30 ft obscured interval to the overlying Brown's Creek Clays. Therefore, it would appear that the Johanna River Sands represent an abbreviated section of the Dilwyn Clay. But one has to consider that Chapman's Sample No. 1 could well be the equivalent of the Princetown Member (at 750 ft in La Trobe), and that the Brown's Creek Clays and Castle Cove Limestone (of Carter 1958) have not been recognized in the La Trobe section.

CASTLE COVE SECTION: 14 ft of Johanna River Sands underlie conformably the Upper Eocene calcareous rocks (Carter l.c.). Here the sands contain a rich assemblage of *Haplophragmoides* cf. *incisa*, *H.* cf. *paupera*, and *H. rotundata*, which strongly supports the contention that the upper part of the Johanna River Sands is of Upper Eocene age.

THE TORQUAY TO EASTERN VIEW SECTION: Although this section is on the E. side of the Otway Ra., comment is necessary in the light of Raggatt & Crespin's (l.c.) detailed study of the section. The sands and silts of the Demons Bluff Formation near the Village of Anglesea, contain a *Haplophragmoides* fauna which was figured by Crespin (1950) and refigured in Raggatt & Crespin (l.c.). On examining the figured specimens and collected samples, the author determined *H.* cf. *incisa*, *H.* cf. *paupera*, and *H. rotundata*, which are species of the Upper Eocene or younger *Haplophragmoides* assemblage. These localities are stratigraphically below the Jan Juc Limestone (Oligocene) and represent the upper part of the Demons Bluff Formation.

Mr K. J. Reed (Mines Dept unpublished report—1963/71) examined a series of shot hole samples from the Anglesea area. In a few samples of the Demons Bluff Formation he reports some where *Haplophragmoides* spp. is associated with Upper Eocene planktonic Foraminifera. The author has re-examined these samples and finds that they all contain the Upper Eocene *Haplophragmoides* assemblage.

The upper part of the Demons Bluff Formation is considered to be of Upper Eocene age.

PALAEOECOLOGY

The alteration of generic classification from *Cyclammina* to *Haplophragmoides* is of considerable palaeoecological significance and is not merely a pedantic, taxonomic exercise. Akers (1954) has presented bathymetric data to support his contention that *Cyclammina cancellata* Brady is restricted to depths greater than 200 metres in modern oceans, being most abundant below continental shelf depths. 'The species has a widespread distribution in Tertiary rocks, where its presence in conjunction with other criteria suggests an open marine depositional environment at bathyal or near bathyal depths' (Akers, l.c., abstract). Akers (l.c., p. 149) found that this statement is true of the whole genus.

If *Cyclammina* spp. were present in the Dilwyn Clay, then the above statement would contradict environmental interpretations by Baker (1953) and McGowran (1965). The consensus of opinion is that the Dilwyn Clay is a paralic sequence deposited in water which fluctuated from marine to brackish. Neglecting the reports of *Cyclammina*, the foraminiferal evidence indicates fairly shallow shelf to estuarine environments.

On the other hand, *Haplophragmoides* spp. are often represented in shelf deposits and many species of this genus are euryhaline, tolerating low salinity waters of estuarine and marsh environments as discussed by Hiltermann (1963). Therefore, the ecological distribution of *Haplophragmoides* corresponds with the apparent depositional environments of the Dilwyn Clay.

Haplophragmoides spp. are associated with Paleocene faunas in many samples from the La Trobe section. However, only in two samples are they a dominant faunal element. There is 70 per cent *Haplophragmoides* spp. at 950 ft (top of 'Rivernook Fauna') and at 750 ft (Princetown Member). This is in marked contrast with the W. Victorian Upper Cretaceous sequence where Taylor (1964) shows a dominance of this form throughout. Higher in the La Trobe section between 678 and 200 ft, *Haplophragmoides* spp. are the only species present, thus suggesting a decline in marine conditions up the section. A complete environmental study of this section is in preparation.

The depositional environment of both the Johanna River Sands and the Demons Bluff Formation is similar to that of the Dilwyn Clay, but the dominance of *Haplophragmoides* spp. could be taken to indicate that there were few, if any, marine

ingressions within the former two formations. But such a statement cannot be made on outcrop evidence alone, as this paper shows that calcareous Foraminifera may not be preserved in these sediments.

Acknowledgements

References

(Including synonomy references)

AKERS, W. H., 1954. Ecologic aspects and stratigraphic significance of the foraminifer *Cyclammina cancellata*. *J. Paleont.* 28: 132-152.

BAKER, G., 1953. The relationship of the *Cyclammina*-bearing sediments to the older Tertiary deposits south-east of Princetown, Victoria. *Mem. Nat. Mus. (Melbourne)* 18: 125-134.

CARTER, A. N., 1958. Tertiary Foraminifera from the Aire District, Victoria. *Geol. Surv. Vict. Bull.* 55.

CHAPMAN, F., 1904. On some Cainozoic Foraminifera from Brown's Creek, Otway Coast. *Rec. Geol. Surv. Vict.* 1: 227-230.

————, 1926. Cretaceous and Tertiary Foraminifera of New Zealand. *N.Z. Geol. Surv. Pal. Bull.* 11.

CHAPMAN, F., and CRESPIN, I., 1930. Rare Foraminifera from deep borings in the Victorian Tertiaries. Part II. *Proc. Roy. Soc. Vict.* 43: 96-100.

———— ————, 1932. The Tertiary geology of the East Gippsland. *Bur. Min. Resour. Aust. Bull.* 1.

CRESPIN, I., 1950. Some Tertiary Foraminifera from Victoria. *Contri. Cushman Fdn.* 1: 70-74

EDWARDS, A. B., and BAKER, G., 1951. Some occurrences of supergene iron sulphides in relation to their environments of deposition. *J. Sed. Petr.* 21: 34-46.

HARRIS, W. K., 1965. Basal Tertiary microfloras from the Princetown area, Victoria, Australia. *Palaeontographica* B. (in press)

HEDLEY, R. H., 1963. Cement and iron in arenaceous Foraminifera. *Micropaleontology* 9: 433-441.

HILTERMANN, H., 1963. Erkennung fossiler Brackwasser-sedimente unter bessonderer Berucksichtigung der Foraminiferen. *Fortschr. Geol. Rheinld. Westf. Bd.* 10: 49-52.

HORNIBROOK, N. DEB., 1961. Tertiary Foraminifera from the Oamaru District (N.Z.). Part 1 Systematics and Distribution. *N.Z. Geol. Surv. Pal. Bull.* 34.

LOEBLICH, A. R., and TAPPAN, H., 1964. Protista 2—Sarcodina—chiefly 'Thecamoebians' and Foraminiferida. *Geol. Soc. Am., Treatise Invert. Paleont.* C: 1.

LUDBROOK, N. H., 1963. Correlation of the Tertiary rocks of South Australia. *Trans. Roy. Soc. S. Aust.* 87: 7-15.

MAYNC, W., 1952. Critical taxonomic study and nomenclatural revision of the Lituolidae based upon the prototype of the family, *Lituola nautiloidea* Lamarch, 1804. *Contri. Cushman Fdn.* 3: 35-55.

McGowran, B., 1965. Two Paleocene foraminiferal faunas from the Wangerrip Group, Pebble Point coastal section, western Victoria. *Proc. Roy. Soc. Vict.* 79. (in press)

RAGGATT, H. G., and CRESPIN, I., 1955. Stratigraphy of the Tertiary rocks between Torquay and Eastern View, Victoria. *Proc. Roy. Soc. Vict.* 67: 75-142.

STACHE, G., 1864. Die Foraminiferen der Tertiare Mergels des Whaingaroa-Hafens (Prov. Auckland). *Novara Exped. Rept. Geol.* Theil 1.

TAYLOR, D. J., 1964. Foraminifera and the stratigraphy of the western Victorian Cretaceous sediments. *Proc. Roy. Soc. Vict.* 77: 535-603.